

SOUTHEAST COAST NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHEAST COAST NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0 , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHEAST COAST NETWORK

Park	Code	State	Risk	O3 Data
Canaveral NS	CANA	FL	low	kriged
Cape Hatteras NS	CAHA	NC	moderate	kriged
Cape Lookout NS	CALO	NC	moderate	kriged
Castillo de San Marcos NM	CASA	FL	low	kriged
Chattahoochee River NRA	CHAT	GA	high	kriged
Congaree Swamp NM	COSW	SC	low	monitored
Cumberland Island NS	CUIS	GA	low	kriged
Fort Caroline NM	FOCA	FL	low	kriged
Fort Frederica NM	FOFR	GA	low	kriged
Fort Matanzas NM	FOMA	FL	low	kriged
Fort Pulaski NM	FOPU	GA	low	kriged
Fort Sumter NM	FOSU	SC	low	kriged
Horseshoe Bend NMP	HOBE	AL	moderate	kriged
Kennesaw Mountain NBP	KEMO	GA	high	kriged
Moore's Creek NB	MOCR	NC	moderate	kriged
Ocmulgee NM	OCMU	GA	high	kriged
Timucuan Ecol & Hist Preserve	TIMU	FL	low	kriged

CANAVERAL NATIONAL SEASHORE (CANA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CANA					
	1995	1996	1997	1998	1999
Sum06	10	6	10	24	16
W126	14.5	13.1	19.0	27.6	19.0
N60	232	189	321	466	319
N80	12	11	24	75	32
N100	0	0	1	7	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CANA					
	1995	1996	1997	1998	1999
Month 1	0.16	5.61	1.63	-2.38	-1.79
Month 2	-0.87	0.02	-0.89	-2.88	-2.08
Month 3	1.59	-0.75	0.05	-5.73	-1.09

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CANA					
	1995	1996	1997	1998	1999
April	0.16	0.02	1.63	-2.38	-2.08
May	-0.87	-0.75	-0.89	-2.88	-1.09
June	1.59	0.82	0.05	-5.73	0.73
July	-0.71	-2.95	-0.26	-1.67	-2.60
August	2.08	-0.13	-0.34	-2.41	-2.10
September	-0.65	-1.65	-0.15	0.50	0.34
October	2.53	0.65	1.49	-2.50	1.60

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest exposures, 1998 and 1999, each had three months of mild to severe drought. The three remaining years with lower levels of exposure had normal soil moisture conditions. Soil moisture levels associated

with the seasonal W126 index also appear inversely related to ozone concentrations, but the association is not consistent. The year with the highest ozone exposure value, 1998, had six months of mild to severe drought. The two years with mid-level exposures, 1997 and 1999, had normal moisture conditions and four months of mild and moderate drought, respectively. There were normal moisture conditions in 1995, the second lowest exposure year, and two months of mild and moderate drought in 1996, the lowest exposure year.

The low levels of ozone exposure and accompanying soil moisture conditions at Canaveral National Seashore make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone occasionally exceeded 80 ppb and rarely exceed 100 ppb. Low soil moisture conditions constrain the uptake of ozone during higher ozone exposures, and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: black cherry, and American elder.

CAPE HATTERAS NATIONAL SEASHORE (CAHA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CAHA					
	1995	1996	1997	1998	1999
Sum06	21	22	29	30	26
W126	26.8	27.2	39.4	38.8	36.4
N60	494	484	698	705	615
N80	41	49	102	103	112
N100	2	1	7	6	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAHA					
	1995	1996	1997	1998	1999
Month 1	-2.27	-0.20	1.14	-0.27	-0.78
Month 2	-1.01	-0.35	-1.29	0.29	-1.07
Month 3	4.32	1.00	-0.90	-0.42	-0.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CAHA					
	1995	1996	1997	1998	1999
April	-2.27	-0.20	1.14	-0.27	-0.78
May	-1.01	-0.35	-1.29	0.29	-1.07
June	4.32	1.00	-0.90	-0.42	-0.50
July	-1.78	3.72	-0.93	0.01	-1.35
August	-1.03	0.74	-2.47	-0.64	-0.60
September	-0.57	3.54	0.17	-1.17	4.09
October	1.62	2.42	-1.07	-1.72	4.04

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years. The criteria for injury under the W126 exposure index are generally satisfied.
- In three years, the N-values for concentrations of 80 and 100 ppb are significantly higher than in the other two years. In the highest years, the levels of exposure could injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposures were relatively similar over the five years. Soil moisture levels show that three years had one or two months of mild or moderate drought, but there was no association between the levels of ozone and drought. The relatively uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone index and soil moisture, and no association between ozone and drought is apparent in the distributions.

The highest ozone year, 1997, and the second highest year, 1998, had three and two months of mild and moderate drought, respectively. The mid-level exposure year 1999 had two months of mild drought. In 1996, the second lowest year, soil moisture was normal while in 1995, the lowest year, there were four months of mild and moderate drought.

The risk of foliar ozone injury at Cape Hatteras National Seashore is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index satisfies the criteria on occasion. The N-values indicate that in a few years there are frequent exposures to concentrations of ozone greater than 80 ppb, and additional hours of exposure at 100 ppb. The lack of a relationship between level of ozone and soil moisture suggests that conditions favorable for the uptake of ozone occur independently of the levels of exposure. This creates the opportunity for injury when high levels of exposure coincide with favorable soil moisture conditions, such as in 1998 when mild drought occurred late in the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: yellow-poplar, American sycamore, black cherry, American elder, crownbeard, and northern fox grape.

CAPE LOOKOUT NATIONAL SEASHORE (CALO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CALO					
	1995	1996	1997	1998	1999
Sum06	16	15	18	22	23
W126	37.1	36.1	31.0	36.7	38.6
N60	652	650	551	663	716
N80	112	104	62	88	78
N100	18	12	4	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CALO					
	1995	1996	1997	1998	1999
Month 1	-0.61	-0.91	-1.19	1.56	-0.47
Month 2	-2.80	-0.10	-1.71	-0.42	-0.85
Month 3	-0.28	-0.42	-0.81	-0.61	-0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CALO					
	1995	1996	1997	1998	1999
April	-2.80	-0.91	0.74	1.73	-0.85
May	-0.28	-0.10	-1.19	1.56	-0.86
June	6.48	-0.42	-1.71	-0.42	-0.75
July	-1.56	2.26	-0.81	-0.61	-2.05
August	-0.70	0.03	-2.09	1.97	0.16
September	-0.65	4.58	0.81	-1.00	1.70
October	1.70	1.93	-0.86	-1.70	2.44

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours was significantly lower. In some years, these levels of exposure could injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because only three months of drought occurred during the five-year period. The two highest, 1999 and 1998, and the one lowest ozone year, 1996, had favorable conditions throughout. Two months of mild and the one of moderate drought occurred in the mid-level exposure months. Soil moisture levels associated with the seasonal W126 index also appear to be

unrelated to ozone concentration. The highest ozone year, 1999, had one month of moderate drought, and the second highest year, 1995, had two months of mild and moderate drought. Two years with the same mid-level of ozone, 1996 and 1998, had normal conditions and two months of mild drought, respectively. The lowest exposure year, 1997, had three months of mild and moderate drought. No pattern of association between ozone and drought is evident from these observations.

The risk of foliar ozone injury at Cape Lookout National Seashore is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index satisfies the criteria on occasion. The N-values indicate that in some years there are frequent exposures to concentrations of ozone greater than 80 ppb, and significant hours of exposure at 100 ppb. The lack of a relationship between ozone exposure and soil moisture suggests that conditions favorable for the uptake of ozone occur independently of the levels of exposure. The likelihood of foliar injury being produced is greatest when high levels of exposure coincide with favorable soil moisture conditions as in 1996.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: yellow-poplar, black cherry, and northern fox grape.

CASTILLO DE SAN MARCOS NATIONAL MONUMENT (CASA)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CASA					
	1995	1996	1997	1998	1999
Sum06	10	10	11	25	17
W126	14.4	16.0	21.6	28.1	20.0
N60	224	262	377	472	338
N80	15	15	27	86	35
N100	3	1	3	13	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CASA					
	1995	1996	1997	1998	1999
Month 1	1.56	0.10	-0.06	-1.63	-1.68
Month 2	-0.77	-1.59	0.81	-2.80	-1.93
Month 3	2.44	0.72	0.34	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CASA					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the criterion in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had a greater number of hours over 80 ppb and 13 hours above 100 ppb. Overall, the levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest ozone exposure values, 1998 and 1999, each had three months of mild to severe drought. In the three years with lower levels of ozone there was only one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. In the highest ozone years, 1998, there were three months of mild to severe drought. In the two years with intermediate ozone, 1997 and 1999, there was one and five months of mild and moderate stress. The second lowest exposure year, 1996, had two months of mild drought and the lowest year, 1995, had normal soil moisture conditions.

The risk of foliar ozone injury at Castillo De San Marcos National Monument is low. The Sum06 threshold is attained each year, while the W126 threshold is satisfied only in one year. The N-values indicate that exposures to 80 to 100 ppb are generally low. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and further reduces the likelihood of foliar injury. At present, no

ozone-sensitive species have been identified at the site.

CHATTAHOOCHEE RIVER NATIONAL RECREATION AREA (CHAT)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Krigia montana</i>	Mountain dandelion	Asteraceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHAT					
	1995	1996	1997	1998	1999
Sum06	19	16	16	27	37
W126	42.0	37.3	36.1	58.2	60.5
N60	689	631	603	933	944
N80	190	149	143	308	340
N100	55	34	28	91	92

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHAT					
	1995	1996	1997	1998	1999
Month 1	-1.49	-0.95	0.75	-0.96	-2.08
Month 2	-1.24	0.22	1.93	-0.84	-1.77
Month 3	2.87	-1.17	0.62	-2.60	0.17

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHAT					
	1995	1996	1997	1998	1999
April	-1.49	0.22	0.76	4.22	-1.77
May	-1.24	-0.95	0.75	-0.96	0.17
June	2.87	0.22	1.93	-0.84	1.82
July	-2.11	-1.17	0.62	-2.60	-0.23
August	2.84	0.23	-1.40	0.21	-1.21
September	0.01	1.70	2.65	-1.53	-0.59
October	4.86	-1.23	3.20	-2.04	0.96

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is

low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure values, 1999, had two months of mild and moderate drought, and the second highest year, 1998, had one month of moderate drought. The intermediate exposure year 1995 had two months of mild drought. The two years with the lowest levels of ozone, 1996 and 1997, had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is again not consistent. In the highest ozone years, 1999 and 1998, there were two and three months of mild and severe drought, respectively. A year with significantly lower intermediate ozone, 1995, had three months of mild and moderate stress. The lowest ozone years, 1997 and 1996, experienced one and two months, respectively, of mild stress.

The risk of foliar ozone injury to plants at Chattahoochee River National Recreation Area is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions may reduce the likelihood of injury in high exposure years. However, levels of exposure capable of producing foliar injury also occur under conditions of minor drought. The likelihood of foliar injury developing may be greatest during years such as 1996, 1997 and 1999 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought for periods that do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

CONGAREE SWAMP NATIONAL MONUMENT (COSW)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for COSW					
	1995	1996	1997	1998	1999
Sum06	12	12	6	19	18
W126	15.8	12.8	13.9	20.7	25.9
N60	283	225	147	360	444
N80	42	29	10	72	107
N100	2	2	0	8	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at COSW					
	1995	1996	1997	1998	1999
Month 1	-2.49	-0.78	-0.31	0.11	-1.08
Month 2	-1.64	-1.72	2.51	-1.43	0.02
Month 3	4.16	-1.95	1.75	-2.48	-0.78

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at COSW					
	1995	1996	1997	1998	1999
April	-2.49	0.11	1.94	2.18	0.02
May	-1.64	-0.78	-0.31	0.11	-0.78
June	4.16	-1.72	2.51	-1.43	0.51
July	0.08	-1.95	1.75	-2.48	-2.12
August	3.13	-0.17	-1.53	-2.35	-2.84
September	0.71	0.02	1.49	1.34	1.09
October	2.15	0.75	2.33	-1.78	0.23

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the association is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 indices in the highest and second highest years, 1999 and 1998, were similar, and the years experienced two months of mild and moderate drought and one month of mild drought,

respectively. The two mid-ozone years each had two months of mild and moderate drought, while the year with the lowest ozone, 1997, had favorable conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The two highest ozone years, 1999 and 1998, had two months of moderate drought and four months of mild and moderate drought, respectively. The mid-level exposure year 1995 had two months of mild and moderate drought and the two lowest years, 1996 and 1997, had two and one month, respectively, of mild drought.

The risk of foliar ozone injury at the Congaree Swamp National Monument is low. While the threshold level for injury is satisfied by the Sum06 index, there are only occasional exposures to concentrations of ozone greater than 80 ppb and exposures above 100 ppb are rare. The inverse relationship between ozone and soil moisture limits the uptake of ozone during high exposure years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder, and crownbeard.

CUMBERLAND ISLAND NATIONAL SEASHORE (CUIS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CUIS					
	1995	1996	1997	1998	1999
Sum06	7	11	11	21	15
W126	14.1	15.9	20.3	25.1	22.5
N60	227	257	352	422	384
N80	16	12	29	71	39
N100	3	1	2	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CUIS					
	1995	1996	1997	1998	1999
Month 1	4.10	-0.35	-0.14	0.06	0.00
Month 2	0.11	-2.27	0.26	-2.29	-1.82
Month 3	-0.54	-0.97	-1.32	-4.20	0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CUIS					
	1995	1996	1997	1998	1999
April	-1.77	-0.35	0.93	0.06	-1.98
May	-1.50	-2.27	-0.14	-2.29	-2.13
June	2.66	-0.97	0.26	-4.20	2.95
July	-1.95	-2.74	-1.32	-1.17	0.00
August	4.10	-0.25	-0.52	-1.12	-1.82
September	0.11	-0.86	-1.73	0.67	0.86
October	-0.54	2.83	4.20	-0.97	-0.59

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb, but the remaining years had three or fewer hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure values, 1998, had two months of moderate and severe drought. In the year with lowest levels of ozone, 1995, soil moisture was favorable. The intermediate ozone years each had

one month of mild or moderate drought. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the relationship is not consistent. In the highest ozone year, 1998, there were four months of mild to severe drought. The two years with slightly lower ozone, 1999 and 1997, had three and two months, respectively, of mild and moderate drought. The two years with the lowest ozone, 1995 and 1996, had three and two months of drought, respectively. Overall, this pattern of distribution is highly indicative of an inverse relationship, although every year had two or more months of drought.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Cumberland Island National Seashore make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone occasionally exceed 80 ppb, and rarely exceed 100 ppb. Several months of mild to moderate drought occur annually and reduce the effectiveness of the exposures.

If the level of risk should increase in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, American sycamore, black cherry, American elder, and crownbeard.

FORT CAROLINE NATIONAL MONUMENT (FOCA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOCA					
	1995	1996	1997	1998	1999
Sum06	9	12	12	21	14
W126	14.6	17.3	22.1	29.5	20.8
N60	230	291	389	498	352
N80	19	17	31	92	36
N100	4	2	5	17	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOCA					
	1995	1996	1997	1998	1999
Month 1	-0.37	0.10	4.65	-1.63	-1.68
Month 2	1.56	-1.59	-0.06	-2.80	-1.93
Month 3	-0.77	0.72	0.81	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOCA					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had seventeen hours in which the concentration exceeded 100 ppb, however the other years had five or fewer hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest ozone exposure values, 1998 and 1999, each had three months of mild to severe drought. In the two years with mid-level ozone, 1997 and 1996, there were normal soil moisture conditions and one month of mild drought, respectively. The year with the lowest ozone level, 1995, had favorable soil

moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of mild to severe drought. In the two years with next highest ozone, 1997 and 1999, there was one month of moderate drought and five months of mild and moderate drought, respectively. There were two months of mild drought in 1996, the second lowest exposure year, and in 1995 when ozone was the lowest, soil moisture was favorable.

The low levels of ozone exposure at Fort Caroline National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures. Hourly concentrations of ozone occasionally exceed 80 ppb, and the number of hours of exposure to concentrations greater than 100 ppb is generally low.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use black cherry.

FORT FREDERICA NATIONAL MONUMENT (FOFR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOFR					
	1995	1996	1997	1998	1999
Sum06	7	11	12	21	15
W126	14.7	16.5	20.6	25.4	24.4
N60	238	269	356	431	419
N80	18	13	32	69	47
N100	2	1	1	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOFR					
	1995	1996	1997	1998	1999
Month 1	4.10	-0.35	-0.14	0.06	0.00
Month 2	0.11	-2.27	0.26	-2.29	-1.82
Month 3	-0.54	-0.97	-1.32	-4.20	0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOFR					
	1995	1996	1997	1998	1999
April	-1.77	-0.35	0.93	0.06	-1.98
May	-1.50	-2.27	-0.14	-2.29	-2.13
June	2.66	-0.97	0.26	-4.20	2.95
July	-1.95	-2.74	-1.32	-1.17	0.00
August	4.10	-0.25	-0.52	-1.12	-1.82
September	0.11	-0.86	-1.73	0.67	0.86
October	-0.54	2.83	4.20	-0.97	-0.59

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb, however the other years had two or fewer hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure value, 1998, had two months of moderate and severe drought. In the three years with mid-level ozone, there was one month of mild or moderate drought in each. The year with the lowest ozone level, 1995, had favorable soil

moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. In the highest ozone years, 1998 and 1999, there were four and three months, respectively, of mild to severe drought. The remaining three years each had two or three months of mild or moderate drought; there were three months of moderate drought in 1995 when ozone was lowest.

The low levels of ozone exposure and soil moisture conditions at Fort Frederica National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures, and hourly concentrations of ozone seldom exceed 80 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, American sycamore, black cherry, and, crownbeard.

FORT MATANZAS NATIONAL MONUMENT (FOMA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOMA					
	1995	1996	1997	1998	1999
Sum06	9	8	10	19	13
W126	14.6	15.8	21.4	28.0	20.0
N60	230	259	372	470	338
N80	15	15	27	87	35
N100	2	1	3	13	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOMA					
	1995	1996	1997	1998	1999
Month 1	1.56	0.10	-0.06	-1.63	-1.68
Month 2	-0.77	-1.59	0.81	-2.80	-1.93
Month 3	2.44	0.72	0.34	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOMA					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had thirteen hours in which the concentration exceeded 100 ppb, however the other years had three or fewer hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure value, 1998, had three months of mild and severe drought while the next highest year, 1999, had three months of mild drought. The remaining three years had one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure levels,

although the pattern is not consistent. In the highest ozone year, 1998, there were three months of mild to severe drought. The next two highest years, 1997 and 1999, had one and five months of mild and moderate drought, respectively. The next to lowest year, 1996, had two months of mild drought and the lowest year, 1995, had normal soil moisture conditions.

The low levels of ozone exposure and the soil moisture conditions at Fort Matanzas National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures. Hourly concentrations of ozone occasionally exceed 80 ppb, and rarely exceed 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: black cherry and American elder.

FORT PULASKI NATIONAL MONUMENT (FOPU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOPU					
	1995	1996	1997	1998	1999
Sum06	10	12	10	21	18
W126	14.9	17.8	17.7	28.6	27.3
N60	246	299	296	517	475
N80	17	21	20	62	66
N100	1	1	1	6	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOPU					
	1995	1996	1997	1998	1999
Month 1	-1.50	-2.27	-2.71	-2.29	0.00
Month 2	2.66	-0.97	0.93	-4.20	-1.82
Month 3	-1.95	-2.74	-0.14	-1.17	0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOPU					
	1995	1996	1997	1998	1999
April	-1.77	-0.35	0.93	0.06	-1.98
May	-1.50	-2.27	-0.14	-2.29	-2.13
June	2.66	-0.97	0.26	-4.20	2.95
July	-1.95	-2.74	-1.32	-1.17	0.00
August	4.10	-0.25	-0.52	-1.12	-1.82
September	0.11	-0.86	-1.73	0.67	0.86
October	-0.54	2.83	4.20	-0.97	-0.59

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had six hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or seasonal W126 index of ozone exposure and soil moisture status. In the year with the highest Sum06 exposure index, 1998, there were three months of mild to severe drought while the second highest year, 1999, had one month of mild drought. The year with mid-level exposure, 1996, had two months of moderate drought, and 1995 and 1997 had the same exposure index and two months of mild drought and one month of moderate drought, respectively. The highest and second highest W126 exposure years, 1998 and 1999, had four and three months

of mild to severe drought. There were two months of moderate drought and two of mild drought in the mid-level exposure years 1996 and 1997. The lowest exposure year, 1995, had three months of mild drought. Overall the patterns of distribution of drought among the years show no association with either index of exposure.

The low levels of ozone exposure and the soil moisture conditions at Fort Pulaski National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposures over 100 ppb are rare. The occurrence of two to four months of mild to severe drought annually constrains the uptake of ozone by plants and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, and crownbeard.

FORT SUMTER NATIONAL MONUMENT (FOSU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOSU					
	1995	1996	1997	1998	1999
Sum06	8	10	12	23	17
W126	12.1	14.4	16.7	28.0	24.7
N60	181	216	294	503	424
N80	15	21	21	73	67
N100	0	2	1	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOSU					
	1995	1996	1997	1998	1999
Month 1	1.41	-0.25	-2.16	-2.25	-0.69
Month 2	-0.09	-1.09	2.88	-0.78	-2.03
Month 3	3.42	0.38	-0.74	-2.54	1.46

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOSU					
	1995	1996	1997	1998	1999
April	-1.85	-0.05	2.88	2.49	-0.03
May	-2.26	-2.43	-0.74	-0.27	-0.49
June	1.41	-2.20	3.28	-2.25	0.67
July	-0.09	-0.25	0.95	-0.78	-0.69
August	3.42	-1.09	-1.12	-2.54	-2.03
September	0.80	0.38	1.87	0.09	1.46
October	1.44	1.67	1.80	-1.49	1.45

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure value, 1998, had two months of moderate drought, while the next highest year had one month of moderate drought. The two intermediate years each had one month of mild and moderate drought, and the lowest ozone year, 1995, had favorable soil moisture. There does not appear to be any association between the W126 level of ozone exposure and soil moisture. In the highest

ozone year, 1998, there were three months of mild to moderate drought, while the second highest year, 1999, had one month each of moderate drought. The remaining three years, 1997, 1996 and 1995, experienced, in decreasing order of exposure, one, three and two months of mild and moderate drought. The incidence of drought appears unrelated to the W126 levels of ozone over the five-year period.

The low levels of ozone exposure and the soil moisture conditions at Fort Sumter National Monument make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for injury, but the W126 does not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and rarely exceed 100 ppb. Soil moisture conditions of mild to moderate drought constrain the uptake of ozone by plants in most years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry, crownbeard, and northern fox grape.

HORSESHOE BEND NATIONAL MILITARY PARK (HOBE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOBE					
	1995	1996	1997	1998	1999
Sum06	25	18	19	25	32
W126	33.3	26.0	26.2	41.3	44.8
N60	573	444	475	727	768
N80	119	68	55	158	185
N100	21	10	4	28	30

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOBE					
	1995	1996	1997	1998	1999
Month 1	-0.82	-0.53	-0.78	-0.63	-0.53
Month 2	-3.22	-0.96	-0.61	-0.87	-1.30
Month 3	-0.48	-0.59	1.01	-1.61	-1.06

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOBE					
	1995	1996	1997	1998	1999
April	-1.35	-1.01	1.37	0.97	-2.30
May	-2.13	-0.53	0.05	-1.60	-0.11
June	-0.82	-0.96	4.42	-0.63	6.59
July	-3.22	-0.59	-0.78	-0.87	-0.53
August	-0.48	0.09	-0.61	-1.61	-1.30
September	-0.76	2.39	1.01	0.78	-1.06
October	6.37	-0.47	1.28	-1.77	0.17

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- In three years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours was significantly lower. In some years, these levels of exposure could injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure values, 1999, experienced two months of mild drought. The years with intermediate ozone exposure, 1995 and 1998, each had one month of mild or severe drought, while the two years with the lowest exposures experienced favorable soil moisture throughout. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. The highest ozone years, 1999 and 1998, each had three months of mild to moderate drought. There were three months of mild to severe drought in 1995, a mid-level exposure year, and the two years with the lowest levels of ozone experienced one month of mild drought between them.

The risk of foliar ozone injury to plants at Horseshoe Bend National Military Park is moderate. While the levels of ozone exposure generally create the potential for injury, low soil moisture reduces the likelihood of injury developing in the higher ozone years. Since the site is subject to potentially harmful levels of ozone most years, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, and crownbeard.

KENNESAW MOUNTAIN NATIONAL BATTLEFIELD PARK (KEMO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for KEMO					
	1995	1996	1997	1998	1999
Sum06	15	15	16	26	36
W126	42.0	38.0	36.9	59.4	62.2
N60	689	647	626	954	979
N80	190	145	139	308	346
N100	54	32	23	88	87

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at KEMO					
	1995	1996	1997	1998	1999
Month 1	2.87	0.22	0.62	-2.60	-1.21
Month 2	-2.11	-1.17	-1.40	0.21	-0.59
Month 3	2.84	0.23	2.65	-1.53	0.96

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at KEMO					
	1995	1996	1997	1998	1999
April	-1.49	0.22	0.76	4.22	-1.77
May	-1.24	-0.95	0.75	-0.96	0.17
June	2.87	0.22	1.93	-0.84	1.82
July	-2.11	-1.17	0.62	-2.60	-0.23
August	2.84	0.23	-1.40	0.21	-1.21
September	0.01	1.70	2.65	-1.53	-0.59
October	4.86	-1.23	3.20	-2.04	0.96

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There is no association between the 90-day Sum06 accumulation period levels of ozone and soil moisture conditions. Months of mild and moderate drought were

distributed over the five-year period without any relationship to the level of ozone. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not fully consistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In the highest ozone years, 1999 and 1998, there were two and three months, respectively, of mild and moderate drought. In the mid-level exposure year, 1995, there were three months of mild and moderate drought. The second lowest exposure year, 1996, had two months of mild drought, and the lowest year, 1997, had one month of mild drought.

The risk of foliar ozone injury to plants at Kennesaw Mountain National Battlefield Park is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest in years such as 1996, 1997 and 1999 when ozone exposures exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the long-term uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, and northern fox grape.

MOORE'S CREEK NATIONAL BATTLEFIELD (MOCR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MOCR					
	1995	1996	1997	1998	1999
Sum06	10	19	21	35	20
W126	23.5	26.9	34.3	46.4	29.9
N60	440	490	607	842	503
N80	42	51	86	166	101
N100	2	2	4	14	13

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MOCR					
	1995	1996	1997	1998	1999
Month 1	-2.98	-0.47	-1.45	1.02	0.97
Month 2	-0.71	-0.38	-0.56	-1.31	-0.35
Month 3	7.20	2.48	-0.58	-2.71	-2.15

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MOCR					
	1995	1996	1997	1998	1999
April	-2.98	0.23	0.91	2.20	0.32
May	-0.71	-0.47	-1.45	1.02	0.97
June	7.20	-0.38	-0.56	-1.31	-0.35
July	-1.15	2.48	-0.58	-2.71	-2.15
August	-1.64	-0.19	-3.34	2.43	-0.86
September	-0.87	7.28	0.83	-0.48	1.80
October	3.11	3.72	-0.13	-1.38	3.90

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours was significantly lower. In some years, these levels of exposure could injure vegetation.
- There are no associations between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture conditions. In the Sum06 assessment, months of mild and moderate drought were distributed over the five-year period without any relationship to the level of ozone. The highest ozone year, 1998, had one month of mild and one of moderate drought, while the lowest ozone year, 1995, had a month of moderate drought. There is no association

between the W126 index of exposure and soil moisture with one to three months of moderate to severe drought occurring in four of the five years. The years with both the highest and lowest exposure levels, 1998 and 1995, each had three months of mild and moderate drought.

The risk of foliar ozone injury at Moore's Creek National Battlefield is moderate. The Sum06 threshold is satisfied annually while the W126 threshold is satisfied only in the highest exposure years. The N-values indicate that exposures to 80 to 100 ppb vary considerably among years. Months of low soil moisture occur independent of the level of ozone and can significantly constrain the uptake of ozone. The risk of injury may be greatest in years such as 1999 when high levels of ozone coincide with soil moisture conditions that generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, yellow-poplar, American sycamore, black cherry, and American elder.

OCMULGEE NATIONAL MONUMENT (OCMU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for OCMU					
	1995	1996	1997	1998	1999
Sum06	13	10	25	32	42
W126	41.9	34.1	33.9	50.9	53.1
N60	703	573	568	842	836
N80	184	132	130	257	280
N100	46	28	32	61	81

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at OCMU					
	1995	1996	1997	1998	1999
Month 1	2.15	-1.18	-0.09	-2.76	-0.51
Month 2	-2.19	-0.77	-2.00	-3.25	-2.59
Month 3	0.60	0.46	2.14	-1.39	1.20

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at OCMU					
	1995	1996	1997	1998	1999
April	-2.21	-0.58	0.18	2.83	-2.37
May	-2.22	-0.82	-0.11	-1.60	-1.65
June	2.15	-1.18	0.47	-2.76	1.84
July	-2.19	-0.77	-0.09	-3.25	-0.51
August	0.60	0.46	-2.00	-1.39	-2.59
September	-0.32	0.80	2.14	3.77	1.20
October	2.04	0.74	2.62	-1.33	0.20

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest ozone exposure values, 1999 and 1998, had one month of moderate drought and three months of mild to severe drought, respectively. The remaining years each had one month of mild or moderate drought; the year with the lowest ozone had one month of mild drought.

Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1999 and 1998, there were three and five months, respectively, of mild to severe drought. The mid-level ozone year 1995 had three months of moderate drought, and the two years with the lowest levels of ozone each had one month of drought.

The risk of foliar ozone injury to plants at Ocmulgee National Monument is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a high exposure year. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels do not place long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, yellow-poplar, American sycamore, black cherry, American elder, crownbeard, and northern fox grape.

TIMUCUAN ECOLOGICAL AND HISTORIC PRESERVE (TIMU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TIMU					
	1995	1996	1997	1998	1999
Sum06	9	12	12	22	14
W126	14.6	17.3	21.7	29.2	21.2
N60	230	289	379	492	360
N80	19	17	31	90	37
N100	4	2	4	16	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TIMU					
	1995	1996	1997	1998	1999
Month 1	0.63	0.10	-0.06	-1.63	-1.68
Month 2	-0.37	-1.59	0.81	-2.80	-1.93
Month 3	1.56	0.72	0.34	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TIMU					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had sixteen hours in which the concentration exceeded 100 ppb, but there were generally four or fewer hours over 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest ozone exposure levels, 1998 and 1999, each had three months of mild to severe drought. The remaining three years had lower levels of ozone and experienced one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to

ozone concentrations, although the pattern is not consistent. The year with the highest ozone exposure value, 1998, had three months of mild to severe drought. In 1997 and 1999, two years both with the second highest level of exposure, there was one month of moderate and five months of mild and moderate drought, respectively. The second lowest exposure year, 1996, had two months of mild drought, and the lowest year had normal soil moisture conditions.

The low levels of ozone exposure and soil moisture conditions at Timucuan Ecological and Historic Preserve make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied. Hourly concentrations of ozone exceed 80 ppb for a few hours each year and hours of exposure to concentrations greater than 100 ppb are generally low. High ozone exposures occur during periods of low soil moisture that constrain uptake by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, black cherry, and American elder.